Case 11: DETECTION AND PREVENTION OF TOXIC GAS ACCIDENTS IN SALT WELLS OF KUTCH REGION

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Summary:

Generation of toxic gases in brine wells is a very frequent phenomenon. Every year there are numerous cases of accidents including fatalities resulting from harmful gases. Although there are industrial detectors available for toxic gas sensing, the high cost of such systems make them beyond reach of the salt farmers, who are one of the poorest section of 'producers' in our country.

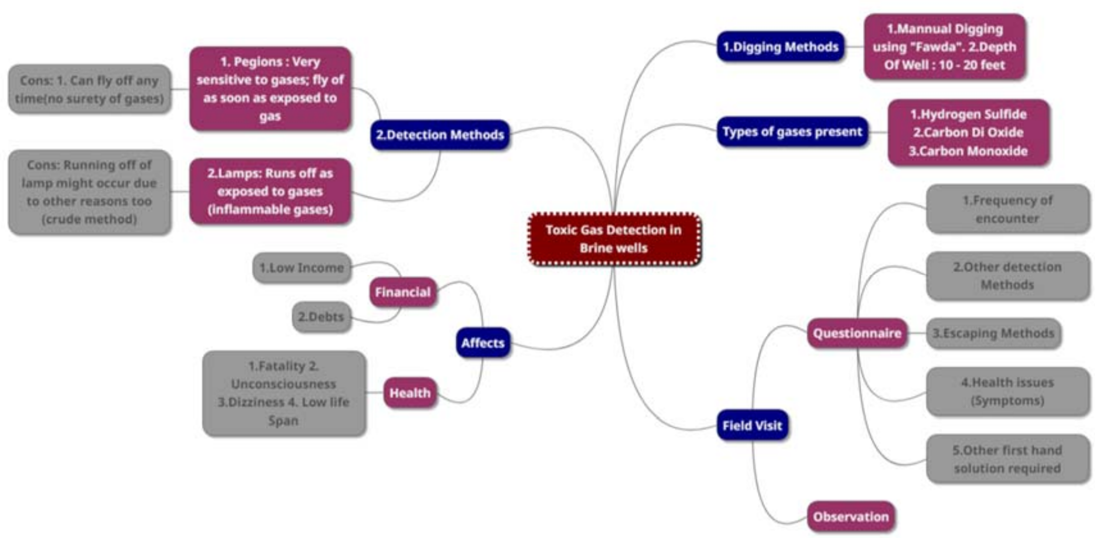
So, we did a literature search to find various harmful gases that are generated in salt wells of Little Kutch region. However, we were surprised to find no study specific to Kutch area for this problem. But there are reported incidents of carbon monoxide, carbon dioxide and hydrogen sulphide poisoning in other wells and sewages across the globe. During our first field visit to Rann of Kutch, we talked to a group of salt farmers and one survivor (Ganpat bhai) for understanding the before and after effects of such accidents. Combining all inputs from prior art search, inspection of actual brine well sites, lab sample test and the farmers feedback, we concluded that hydrogen sulphide(H2S) is the prime cause for toxicity, although presence of other gases like carbon monoxide cannot be ruled out. But we were sure of hydrogen sulphide and thus took the challenge of designing a cost effective solution to detect H2S during this summer school. We decided to tackle the problem from two approaches- one using commercially available gas sensors and other by using basic chemical test method.

We came up with a very cheap (one rupee per test) paper based colour test method to detect H2S presence. The strip changes its colour when it comes in contact with H2S. To make the system more effective and robust, we designed an electronic system using a pair of simple light transducer and discrete electronic components that generates an alarm whenever the colour of this strip changes. The cost of all the discrete components together stands around 100 rupees. We tested the device in lab repeatedly and were thrilled to find a true alarm every time the system was subjected to H2S environment. During our brainstorming sessions and group discussions, we also discussed on possibility of a first-hand measure for providing little extra escape time to the person inside the well if a positive alarm is triggered and gas is detected. So we also made a simple gas mask using membrane cloth and activated charcoal, which is an effective H2S adsorbent. It can easily be replicated by anyone in home and is also very economic. So on our second field visit for testing the systems on real environment, we went to two different sites and inspected 7-8 wells. In first site, the water level was hardly couple of feet deep from surface, thus chance of gas presence was very limited. From one well where we detected presence of H2S during our first visit, we did get a positive detection of H2S using the colour strip but the concentration was very small. Also, we did get a good rise in carbon monoxide level reading from electronic sensor. Then we went for 2nd field, almost 30 km far from first site, where the wells were deeper (20 to 30 feet) and reports of occurrence of toxic gas accidents were more frequent. However, being

an off season, all the bore wells were left covered with 3-4 feet of muds. We tried digging it by hand but were unsuccessful and so could not test our system there either. We happened to meet Veer Singh Ji, who was one of the farmers we talked to during our first visit. We demonstrated all our prototypes to him in field, and he liked the solutions, especially the idea of the pipe lid design.

Problem Definition:

Every year salt farmers in the Kutch region dig wells to extract brine water which they evaporate to extract salt. The process of well digging is that they first dig a well of depth around 10-15 feet. Looking at the texture and the moisture of the soil they judge the presence of water. If there is a possibility of presence of water they further bore into the ground to reach the water table. During the processes of boring or extracting brine water, gases produced due to anaerobic respiration such as hydrogen sulphide, carbon monoxide and methane are released with a lot of pressure. The farmers inside the well generally cannot detect the presence of these gases and could come out. However the ejection of these gases causes drop in oxygen concentration. Gases like carbon monoxide and hydrogen sulphide further combine with our haemoglobin and reduce the oxygen carrying capacity of our blood. The farmers suffer from asphyxiation and many times lose their lives. The problem was the detection of these gases and device a mechanism which would help the farmers in these situations. As can be understood this issue is serious and needs to be addressed immediately. Every year many farmers succumb to these gases leaving behind their widowed wives and children in eternal pain. Very few farmers are lucky enough to face the gas attack and still see the sunrise of the next day and those who do survive have no idea of what happened to them except the faint remembrance of dizziness and then complete darkness.



Mind Map

Field visit:

The team left for the Rann in the morning at around 4 o'clock. The journey took around 6 hours and by 10 we reached Kharaghoda which is a part of the Little Rann of Kutch. There we were received by Ambu Bhai, a local. His father was a salt farmer and he had done some salt farming in his childhood, due to which he was an asset for our enquiry. He told many things about the Rann, It is a barren land of salty mud which stretches over the area of about 5000 square kilometre. There is almost no vegetation there because of the high concentration of salt in the soil.

After the monsoons, from the month of October, the salt farmers dig wells there in order to get the salty water which is used by them in the extraction of salt. This was an issue since there was no salt farming during our visit, benefiting us of having a hand on experience of salt farming. The depth of the well varies from a couple of feet to around 15 feet. Steps were made in the well by digging out mud for going in and out the well. After that they bore deeper to around 60 feet to get the brine water, which then goes through a number of processes before the salt is obtained. When we asked Ambu bhai about how do the salt farmers determine the best where they should dig, he told us that there is no logic behind it and that it was like a ‘lucky draw’. Thus many times the farmers dig a well to find no water inside it.

During the processes of digging and boring toxic gases are released. The farmers working inside the well suddenly become dizzy and unconscious due to which they are unable to escape timely. This results in the death of many salt farmers every year. Again, the depths when the gases would evolve and their toxicity is uncertain, making it difficult for the farmers of predicts the event and use the necessary precautions. Ambu Bhai also told us about a certain Ganpat Bhai who was a victim of the exposure to these toxic gases. He was provided with timely medical assistance due to which he survived. We decided to visit the village where the Agarias live to know more about these toxic gases and know about the experience of Ganpat bhai, which could be very helpful in our quest. There we saw some wells dug which were not in use at that time and then we went to stay at the guest house of Gantar, an NGO committed to the education of the children of Agarias and other such issues

The mighty Kutch

We were greeted by around 10-15 Agarias when we visited their village. Ganpat Bhai was not there when we reached but he soon joined. The information which we get there was very useful.They told us that it was their experience that when a well is freshly dug and bored, there are no cases of toxic gases. But when they come to the well the next year and remove the cloth from the mouth of the pipe, there is a rapid evolution of toxic gases. In order to detect the gas the farmers lower a lighted stick into the well. If the stick extinguishes, then there is presence of toxic gases. They tie ropes around the waist of the person going into the well so that he can be pulled out in case toxic gases start coming out. But these precautions are seldom observed by the farmers and they do such practices only after some such events have already occurred. Then we learnt what happened to Ganpat Bhai

He told us that when he was inside the well he suddenly started feeling dizzy and become unconscious after sometime, due to which he was unable to speak and ask for help. The farmers outside the well had a hard time saving him. Since he was not tied to any rope, the farmers sent a person in the well to tie rope around his waist. But as soon as this person reached the bottom he also became unconscious. He was brought out immediately till he regained his consciousness after which he was again sent down. Finally they were able to bring Ganpat bhai out of the well. This happened three times due to which the rescue operation took around one and a half hour. Finally they were able to bring Ganpat bhai out of the well. He was immediately rushed to a hospital in the nearby city where he was treated and given oxygen. The timely help provided helped him in regaining his consciousness. He told us that he did not feel any odour of the gas when he was inside the well.

A typical Dug cum Bore well in Kutch region

Based on the descriptions provided by the farmers we came to know that the gas was extremely toxic, it was odourless and did not support combustion because a lighted stick thrown in the well was observed to be extinguished. Carbon monoxide was the prime contender of being this mysterious toxic gas. We also suspected the presence of hydrocarbons like methane because they are odourless and are found at places like these.

The next day we again went to the field with the aim to get some samples of the well water and know more about the gases that come out of these wells. We met Veer Singh, an Agaria, who agreed to help us. He took us to his well which was quite shallow compared to the wells we had seen the day earlier. He removed the cloth which was used to cover the pipe bored into the ground. As soon as the cloth was removed we smelt the unmistakable foul smell of hydrogen sulphide. This was a surprise since we were earlier told that the gas was odourless. We took the samples of the soil on the outer surface as well as from the depth of around 2 feet. We also took the water from the well in a bottle which contained the dissolved hydrogen sulphide. We then went to the village dispensary to gain some insight into the effects of the gas. The doctor told us that the main diseases prevalent among the salt farmers are asthma, hypertension. He also told us that many people have come to the village in the past with similar questions but no steps have ever been taken.

We then visited the residence of Ganpat bhai and asked him to smell the gases coming from the water collected in the bottle. Surprisingly he said that he could not smell anything even though we could clearly smell the foul odour. This showed that due to exposure over a long period of time these farmers have become accustomed to the smell of the gases. It was an unexpected observation which led us to conclude that the major gas present in the well is hydrogen sulphide but the farmers could not detect it because they have become accustomed to the foul odour of this gas. Meanwhile we took the water sample and from the well with the hope that chemical analysis of the sample would give us information about the other gases present inside the wells along with their concentrations. However when we reached the lab we found that all there were no gases present which made us conclude that the gases, if present, have already escaped the water in the bottle.

Design concept

After returning we embarked upon the path of finding a way for detection of gases. From the information we gained from the field we knew that the gases present in the well were toxic. We were confirmed that hydrogen sulphide was present along with the possibility of carbon monoxide and hydrocarbons. We needed to know more about the properties of the gases and how can we devise methods to detect.

For having a better understanding of the toxic gases we went to Gujarat Forensic Science University. There we had a meeting with Mr. Mohinder Singh Dahia, Director of GFSU. We told him about the situation and sought his advice. He proved to be a very cooperative person. He first and explained us the process through which these gases are formed underground. He also told us that similar gases are formed in the gutters and affect the sewage workers. We told about the gases that we suspect to be present in the well, to which he agreed, with strong emphasis on the presence of carbon monoxide. For the detection of hydrogen sulphide he suggested that we can use a chemical based approach and find some chemical that gives a positive test for hydrogen sulphide. He further suggested that we can make paper strips of the chemicals and use them on the site for the detection of the gases. We asked him if he can provide us with a source hydrogen sulphide to perform the chemical tests and know about its chemical properties, to which he smilingly refused saying that they do not perform tests on gases in the forensic lab.

Lid for the bore with a slider

On the same day Professor Amit Sheth, HOD of the Department of Design at the Nirma University visited the summer school. We asked him about the design that our prototype should have to cater to the need at hand. Currently the farmers cover the opening of the bore pipe with a cloth at the end of the farming season, which they remove when they come to extract the brine water the next year. Now what happens is that the toxic gases, formed as a result of anaerobic respiration, get accumulated in the pipe. When the farmers remove the cloth these gases come out with a lot of pressure and knocks down the farmers at times. The problem we presented before him was how could we detect the presence of gases trapped in the pipe without removing the cloth. He gave some very good solutions for this problem. He suggested that we could use a mechanism similar to that used in the talcum powders, where there is a cover with a sliding lid. The cover has holes on half of the surface while other half is covered. The slider can be moved on the holed surface to prevent the escape of powder from the container. He also suggested that we use an injection to lower the chemical or the sensor inside the hole without removing the cloth so that the gas is detected without causing any harm to the person. We liked the cover idea very much and decided to go further with it.

We had a Skype session with Mr. Sanjay Sharma, associate professor in Mechanical Department . He agreed with our observations during the field visit and also provided us with a very important insight. He told us that hydrogen sulphide has a very foul smell of rotten eggs. But if the gas is in a high concentration, it affects our olfactory system and weakens our smell of sense. Then we recalled a detail we missed during the field visit. When the farmer removed the cloth from the well and the gases were ejected, we immediately smelt the foul smell of hydrogen sulphide. But the farmer who was with us did not smell the gas. Back at that time we ignored this but on getting this detail, the incident was justified.

Next we talked to Ted Mollam, who has been a fellow student at MIT. We told him about the problem and our approaches towards solving it. He was very excited with our findings and our approaches. We showed him the sensor based project that we had built till that time built on arduino uno. He suggested us to make the project as cost effective as possible because the economic conditions of the farmers is not very good. He advised us to use arduino nano which is cheaper and smaller than uno. We found his advice to be useful and decided to implement it. So we start working to replace uno with nano in our project.

Development of Prototype

The suggestions provided by the mentors helped us with our further approach towards the problem. We worked upon the suggestions of Mr. Dahia and did a study on the properties of hydrogen sulphide to know about its chemical and physical properties. We found that the gas gives the colourless solution of lead acetate brown. This could be used for the detection of the gas. So we prepared paper strips dipped in the solution of lead acetate. For making hydrogen sulphide, we used Kipps apparatus in which ferrous sulphide was reacted with concentrated hydrochloric acid to yield hydrogen sulphide. The test was successful, so we decided to go forward with it. There was however one problem with this. The water used in this region is very salty and contains a lot of chloride ions. When we made lead acetate solution, a lot of salt precipitated as white lead chloride. This reduces the solubility and hence the concentration of the solution. For this we began searching for a chemical that is cheap, does not precipitate in the presence of chloride ions and gives a change in colour in the presence of hydrogen sulphide and should be easily available. The compound which fulfilled all these criteria was found to be hydrated copper sulphate, commonly called as blue vitriol. It changes its colour from blue to black in the presence of hydrogen sulphide, it dissolves in the presence of chloride ions, is commercially available and completely affordable. So we prepared the strips of copper sulphate of one molar concentration. The strips showed excellent colour change in the presence of hydrogen sulphide. The reaction was possible even when the strips were completely dry, because the gas produced was moist.

During the preliminary phase of development of the project, the major question was the type of gas that was found in the area as it wasn't clear even from the visit of the local medical centre about the details of the gas. Therefore, for the preliminary part of the research, we made a device consisting of several different types of gas sensors that were quite specific to one aspect of the mixture of the gas. Among all of these, we had our suspicions over the gas of H2S (hydrogen sulphide) and Carbon monoxide due to the following reasons.

1. Carbon monoxide was odourless and the gas that was told to us about by the people was also said to be odourless.
2. Hydrogen Sulphide though wasn't odourless and has a distinct rotten egg smell, in higher concentration tends to cause loosening of the sense of smelling to the people that are being affected by it making it seem like it's an odorless gas.

In order to find out the right gas, we tested two gas sensors, MQ135 and MQ7 which were quite particular in finding out specifically the gas that was present in the gas wells. Apart from just moving forward on this project from the electronics aspect we were also taking into consideration the possibility of using a chemical sensor in order to carry out the diagnose. Therefore, we prepared another chemical based sensor in order to detect gas specifically designed for H2S.

For the preparation of the electronics module for finding out the specific gas that was present in the well, we used an Arduino Uno Board with a small buzzer that would only beep if the

concentration of the gas is present above a particular value that was calibrated after going to the site of the wells.
Furthermore, for the preparation of the chemical based sensor, we used lead acetate strips that were found to react with hydrogen sulphide gas in order to give a black precipitate. The same reaction used to turn the strips black due to the reaction. However, as it wasn't enough to know whether that concentration of the gas is harmful or not, we installed a photodiode and a comparator circuit which basically used to convert the amount of reaction that has been carried out in between the strip and the gas present. The calibration of the same can be done by simple adjusting the value at which the sensor should activate the buzzer to beep.

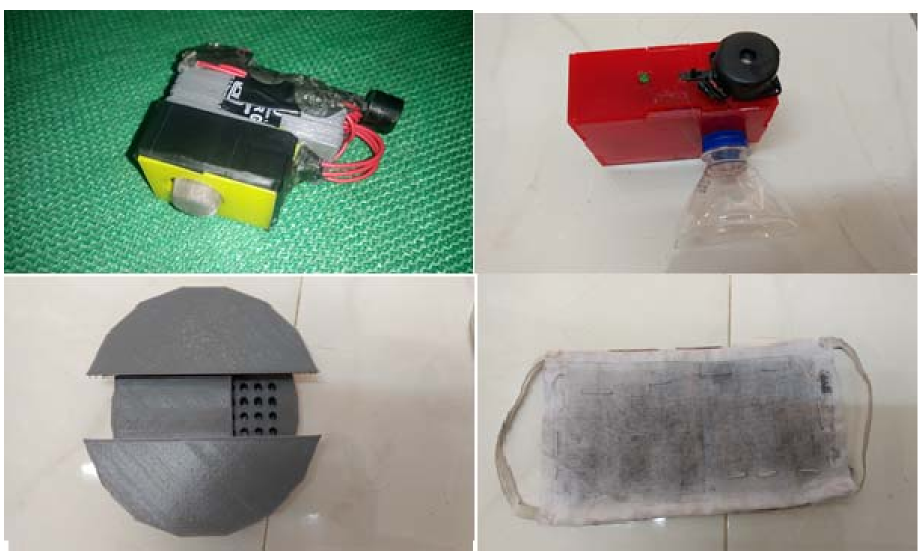
Testing of the prototypes (Gas Detection):

After both of the prototypes were made, they were taken to the site in order to find out the toxic gas that was present. Initial testing related to the prototype was done by preparing H2S using Kipp's Apparatus in lab where the MQ135 sensor showed higher analog signal value (around 800 compared to its normal value, around 200) with the analog signal value from the MQ7 being almost the same with not much increase (around 300, compared to its normal value, around 200). Once, the preliminary testing was done, while carrying out the same in the field, the prototype showed a significant increase in the analog signal value for the MQ7 sensor (around 500-600, compared to its normal value, 200), with the other sensor MQ135 not showing any significant increase (around 300, compared to its normal value of around 200).
As a result it was found that there is a presence of a mixture of gases there with a major percentage of it being Carbon Monoxide along with presence of H2S.

User Review:
We showed our prototypes to Mr. Veer Singh, an Agaria, who was the owner of the wells and accompanied us to the wells. He was very glad when the solutions to the problems that he has been seeing around him for years. He said that the prototypes are good and he could use them if they are affordable. We asked him the expected price for the sensors. He gave a range of 500-1000 INR which was much greater than the price at which we intended to market the products, which was in the range of 200-300 INR. He also praised the lid that we had made and said that it is better than the cloth that they use or covering the bore. We could not get reviews from any other farmer because it was an off season when we visited the field and there was no farming going on. Nevertheless the reviews we got from Veer Singh were inspiring and encouraged us to improve our design.

Demonstrating the prototypes to farmers

Final Prototype:



Being a part of the system that targets to improve the quality of life of salt farmers gives us satisfaction, both socially as well as morally because:

“ हमने कच्छ का नमक खाया हैं "

Bill of material for final prototype

The cost analysis of our final product is as follows

Electronic Sensor

Sr No.	Component	Quantity	Unit Price	Total price
1	MQ 135	1	200	200
2	Arduino Nano	1	180	180
3	Buzzer	1	20	20
4	9V battery	1	15	15

Total Price: Rs 415

Chemical Sensor

Sr No.	Component	Quantity	Unit Price	Total price
1	LDR	2	8	16
2	LM324	1	10	10
3	Buzzer	1	25	25
4	Battery (9V)	1	15	15
5	LED	3	1	3
6	Trimming Pot	2	5	10
7	Switch	1	3	3
8	Paper Strip	1	1(approx..)	1

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Total price: Rs 83

Pipe Lid: Rs 200 (approx.)
Gas Mask: Rs 20 (approx.)